

STELLAR YIELDS AND CHEMICAL EVOLUTION

The solar neighborhood as a calibrator

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Abstract. Uncertainties in stellar nucleosynthesis and their impact on models of chemical evolution are discussed. Comparing the Type II supernova nucleosynthesis prescriptions from Woosley & Weaver (1995) and Thielemann, Nomoto, & Hashimoto (1996), it turns out that the latter predict higher Mg/Fe ratios that are more favorable in reproducing the observed abundance features of the Milky Way. Provided that chemical evolution models are calibrated on the solar neighborhood, they offer a powerful tool to constrain structure formation. In particular, galaxy formation models that yield star formation histories significantly longer than 1 Gyr fail to reproduce the super-solar Mg/Fe ratios observed in elliptical galaxies.

1. Introduction

Population synthesis models based on *solar* abundance ratios predict – for a given Fe index – Mg indices that are weaker than measured in the integrated spectra of elliptical galaxies (e.g. Worthey, Faber & González 1992 [33]; Davies, Sadler & Peletier 1993 [3]; Mehlert et al. 2000 [18]). Although the link from line indices to element abundance ratios is not straightforward (Greggio 1997 [9]; Tantalo, Chiosi, & Bressan 1998 [23]), the strong Mg absorption features are interpreted as an enhancement of α -elements. More quantitative studies find an average [Mg/Fe] overabundance of 0.3–0.4 dex (Weiss, Peletier, & Matteucci 1995 [31]; Greggio 1997 [9]). This conclusion

gets further support from the detection of enhancement of Mg and other α -elements in the stars of the Milky Way bulge (McWilliam & Rich 1994 [17]). These findings imply short formation timescales and/or an initial mass function (IMF) that is flat at the high-mass end (Matteucci 1994 [15]). Scenarios that form elliptical galaxies in mergers of evolved spirals fail to reproduce such α -enhanced stellar populations unless a significant flattening of the IMF is assumed (Thomas, Greggio, & Bender 1999 [27]). Galaxy formation models that are based on hierarchical clustering lead to extended star formation histories in elliptical galaxies which produces Mg/Fe element ratios that are too low compared to the values quoted above (Bender 1996 [1]; Thomas 1999 [25]; Thomas & Kauffmann 2000 [28]).

In this paper we address the question of how robust the predictions from chemical evolution models are. For this purpose we analyze two recent Type II supernova (SNII) nucleosynthesis prescriptions (Woosley & Weaver 1995 [32], hereafter WW95; Thielemann, Nomoto, & Hashimoto 1996 [24] and Nomoto et al. 1997 [19], hereafter TNH96), that represent a crucial input for the determination of Mg/Fe element ratios as a function of timescales (see also Gibson 1997 [6]; Portinari, Chiosi, & Bressan 1998 [21]).

2. Stellar yields

The ratio of Mg to Fe is a measure for the contribution from high-mass stars to the chemical enrichment, because Mg is only produced in SNII (short-lived, massive stars), while a significant part of Fe comes from Type Ia supernovae (SNIa, low-mass, long-lived binary systems). The crucial input ingredients to calculate the enrichment of these elements are both the supernova rates and the stellar yields (nucleosynthesis and ejection per supernova, see Chieffi, this volume; Limongi, this volume). In the following we briefly comment on the SNII yields of Mg and Fe that are calculated by WW95 and TNH96 (see also Thomas, Greggio, & Bender 1998 [26]).

Magnesium Magnesium is produced in both hydrostatic (before the explosion) and explosive carbon burning. The synthesis thus depends upon the (still uncertain) parameters of stellar evolution (convection criteria, $^{12}\text{C}(\alpha, \gamma)^{16}\text{O}$ -rate, etc.) and the modeling of the explosion. We find that the yields of Mg in the two sets of models are in good agreement for low initial stellar masses in the range $10 - 18 M_{\odot}$. In a $20 M_{\odot}$ star, instead, TNH96 produce significantly more Mg than WW95, likely because they adopt the Schwarzschild criterion for convection (WW95; Thomas et al. 1998 [26]). At the high-mass end ($30 - 70 M_{\odot}$), the total mass and the composition of the ejecta mainly depend on the explosion energy and on the mass-cut, which leads to slightly higher Mg-yields in the TNH96 models.

Iron Since the iron *ejected* by SNeII is entirely produced during the explosion, the yield is very sensitive to details of the explosion model (total energy, mass-cut, fall-back effect, energy transport, etc.). Hence, particularly at higher masses, the Fe-yields from SNeII are very uncertain. For $M < 35 M_{\odot}$, WW95 (model B) give higher Fe yields than TNH96.

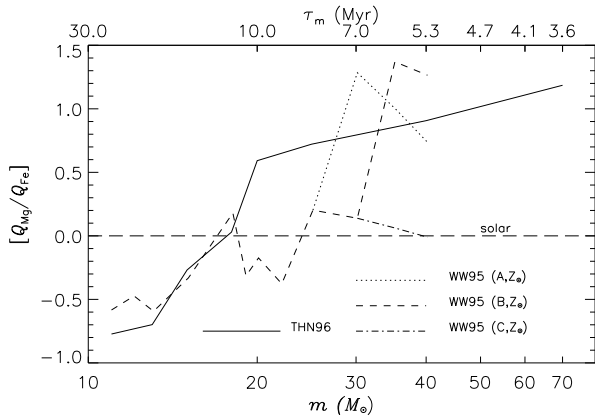


Figure 1. [Mg/Fe] ratio in the ejecta of SNeII explosions as a function of initial stellar mass. WW95 with solar initial metallicity are considered. WW95 models A,B,C assume different explosion energies for the high-mass stars increasing from model A to C. Model B is equivalent to the prescription in TNH96.

Fig. 1 shows the resulting [Mg/Fe] ratio in the SNeII ejecta for the two nucleosynthesis prescriptions WW95 and TNH96. For $M \sim 20 M_{\odot}$, the [Mg/Fe] predicted by TNH96 is ~ 1 dex higher than WW95. At the high-mass end, WW95 (model B) produce larger Mg/Fe because of the very low Fe yield due to the fall-back effect.

3. The solar neighborhood

The significant discrepancies between the Mg/Fe yields from WW95 and TNH96 lead to very different conclusions on star formation timescales and IMF slopes (Thomas et al. 1998 [26], 1999 [27]). It is therefore crucial to calibrate the chemical evolution model on the abundance patterns of the solar neighborhood, for which the observational data provide the most detailed information. Here we show the impact of the above discrepancies in the stellar yields on the evolution of [Mg/Fe] with [Fe/H] in the solar neighborhood. The model description for the chemical evolution in the Milky Way is based on the standard infall model (Matteucci & Greggio 1986 [16]). The

recipe for the rate of SNIa is taken from Greggio & Renzini (1983) [10], a Salpeter initial mass function ($x = 1.35$, $M_{\min} = 0.1 M_{\odot}$, $M_{\max} = 70 M_{\odot}$) is adopted. For more details see Thomas et al. (1998) [26].

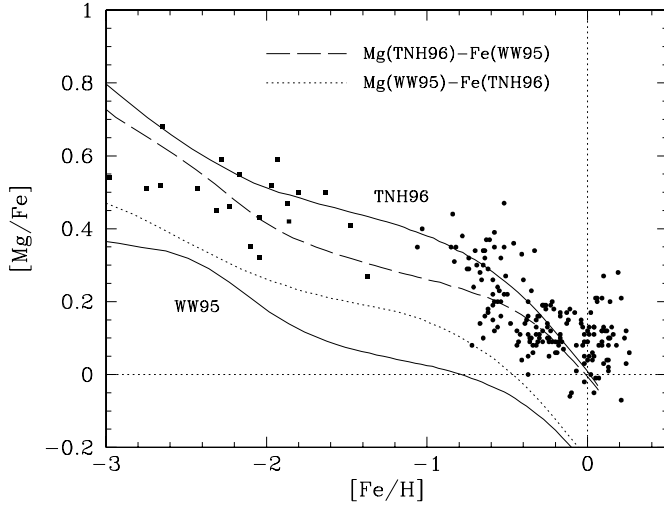


Figure 2. $[\text{Mg}/\text{Fe}]$ ratio as a function of iron abundance $[\text{Fe}/\text{H}]$ in the solar neighborhood. Data are from Magain 1989 (squares) and Edvardsson et al. 1993 (circles). The solid lines denote models using SNII-yields from WW95 and TNH96. The broken lines show the case for mixed stellar yields. $\text{Mg}(\text{TNH96})\text{-Fe}(\text{WW95})$: dashed; $\text{Mg}(\text{WW95})\text{-Fe}(\text{TNH96})$: dotted.

Fig. 2 shows observed stellar abundance ratios in the $[\text{Mg}/\text{Fe}]\text{-}[\text{Fe}/\text{H}]$ plane. Models using the same input parameters but different sets of SNII nucleosynthesis prescriptions (WW95 and TNH96) are plotted as solid lines. With the TNH96-yields, the Mg-enhancement in the (metal-poor) halo stars ($[\text{Fe}/\text{H}] < -1$) is well reproduced. The sharp decrease of $[\text{Mg}/\text{Fe}]$ at $[\text{Fe}/\text{H}] \sim -1$ implies the enrichment from SNIa to be delayed by ~ 1 Gyr (Pagel & Tautvaisiene 1995 [20], this volume) which is well matched with the SNIa model adopted here (see also Greggio 1996 [8]). Adopting WW95 yields without modifying the other input parameters, the resulting Mg/Fe ratios are well below the data for all metallicities (see also Timmes, Woosley, & Weaver 1995 [29]). Note that the strongest constraint on the SNII nucleosynthesis comes from the metal-poor halo stars, while the mismatch around solar metallicity could in principle be improved by adjusting the parameters of the star formation history and of the SNIa rate.

Models with mixed stellar yields, namely, $\text{Mg}(\text{TNH96})\text{-Fe}(\text{WW95})$ and $\text{Mg}(\text{WW95})\text{-Fe}(\text{TNH96})$ are shown by the dashed and dotted lines, respectively. This exercise demonstrates that the low Mg/Fe ratios deduced from the WW95 models is mainly due to the low Mg yields. Especially at the

high metallicity regime, the large Fe SNII-yields from WW95 have only a small effect on the final abundance ratios as a considerable fraction (~ 60 per cent) of Fe comes from SNeIa.

We conclude that the impact of uncertainties in stellar yields on chemical evolution models is not negligible. Chemical evolution models that are applied to the Bulge or extragalactic systems should be carefully calibrated on the solar neighborhood.

4. Discussion

4.1. MODEL IMPROVEMENTS

An important requirement for the successful calibration of chemical evolution models is the accuracy and reliability of abundance and age determinations. Analyzing high quality spectra of galactic stars, Fuhrmann (1998) [5] demonstrates that the scatter in Mg/Fe found by Edvardsson et al. (1993) [4] can be reduced. His data also point towards a more pronounced separation of the various components of the Galaxy, that may require more sophisticated modeling (e.g., two-infall model, Chiappini, Matteucci, & Gratton 1997 [2]).

The determination of the exact timescale for the delayed Fe enrichment from SNIa depends on the star formation history that is constrained through the observationally defined age-metallicity relation. As the latter still suffers from a large scatter, it may be more promising in the future to directly adopt the star formation history that is determined with chromospheric ages (Rocha-Pinto et al. 2000 [22]).

Invoking a metallicity dependence of SNIa rates (Kobayashi et al. 1998 [11]) and the consideration of delayed and inhomogeneous mixing (Malinie et al. 1993 [13]; Thomas et al. 1998 [26]; Tsujimoto, Shigeyama, & Yoshii 1999 [30]) represent further improvements of chemical evolution models.

4.2. CONSTRAINT ON ELLIPTICAL GALAXIES

Unless one allows for a flattening of the IMF, the very high Mg/Fe ratios in elliptical galaxies prohibit the occurrence of late star formation, i.e. induced by a merger (Thomas et al. 1999 [27]). This constraint seems to be at odds with the finding that ellipticals exhibit a considerable scatter in H β line strengths (González 1993 [7]). However, composite stellar population models containing a small fraction of old metal-poor stars allow for an alternative interpretation: Such models succeed in reproducing the strong metallic *and* the strong Balmer lines observed in ellipticals without invoking young ages (Maraston, this volume; Maraston & Thomas 2000 [14]).

Acknowledgments

DT thanks F. Matteucci and F. Giovannelli for a very lively and fruitful workshop. This work was supported by the "Sonderforschungsbereich 375-95 für Astro-Teilchenphysik" of the Deutsche Forschungsgemeinschaft.

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